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SEISMIC REHABILITATION OF TRADITIONAL UN-REINFORCED MASONRY BUILDINGS IN IRAN

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Abstract. *Un-reinforced masonry buildings are a major population of residential and school buildings in Iran which have been shown severe damages during past earthquakes e.g. Bam earthquake in 2003 with at least 26000 fatalities. The most important weaknesses of this sort of buildings are coming form the in-adequate lateral load resisting system and the weakness in the element connections. This kind of construction is not (or rarely) used anymore in urban regions. However, any effort for the seismic rehabilitation of the current buildings can save a reasonable amount of life in a future earthquake. That is, a detailed seismic rehabilitation for a typical un-reinforced masonry building in Iran has been described in this paper. The rehabilitation methodology is based on the ASCE 41-06 standard recommendations but adopted in details for the Iranian traditional masonry construction type. The rehabilitation cost is around thirty percent of the re-construction procedure which is quite promising.*

1 INTRODUCTION

Most of the un-reinforced masonry (URM) buildings in Iran have not been engineered whereas constructed based on experiences. Moreover, the construction of URM buildings varies from country to country in many aspects including material properties, layering methods, floor systems, connections and etc. Therefore, despite a considerable amount of research in the behaviour of masonry buildings subjected to the seismic actions carried out in many countries during last decades [1, 2 and 3], it seems difficult to extrapolate the previous research results in order to predict the seismic behaviour of URM buildings in Iran. It is worth to emphasis that most of the researches have been focused on the behaviour of a single URM wall and the corresponding results cannot be extrapolated to the behaviour of a URM structure.

Most URM buildings, which are more than fifty percent of the buildings population in Iran, are characterized by un-reinforced masonry walls and many openings on exterior walls and either a one-way concrete joist slab or a steel I-beam jack arch slab. The traditional URM buildings usually are limited to the two stories with or without a basement. The steel I-beam jack-arch flooring system was, as shown typically in Figure 1, developed in early Victorian Britain and was used to cover large floor areas at warehouses. By the middle of the twentieth century it became a popular flooring system in many Middle Eastern countries. The popularity of this flooring system stems from its relatively low cost and easy construction process. This old system of flooring has shown robustness under normal gravity loading but serious lacks of criteria for an earthquake resistant slab as shown in Figure 2. An example of bam earthquake, from several cases that this kind of flooring system has been collapsed during sever earthquakes, is shown in Figure 2. As a number of advantages, the traditional jack-arch slabs are still very popular in the Middle East, particularly in Iran where even many medium rise steel framed buildings are still floored by this method. Some of these advantages include; simple construction technique, speed in construction, low cost of construction, availability of materials and workmanship and the possibility of altering the slab after construction. The floor slabs, constructed using the steel I-beam jack arch system, are stable under normal static conditions as the brick arches transfer the gravity loads mainly in compression along the arch to the supporting beams. The load is then transferred along the unconnected parallel steel beams to the supporting walls or beams. The geometric form of the steel I-beam jack-arch system and the load path through the steel beams make the slab act as a one-way system. For the purpose of simplicity the total dead load is usually assumed to be used for the design of the steel beams whereas the brick arches are not taken into the design procedure. The large stresses which usually develop in the brick arches due to the gravity loads and the earthquake out-of-plane dynamic loads are ignored by this assumption. The disadvantages of the traditional steel I-beam jack arch floor system make it inconsistence for the seismic loads. The inconsistency of the floor prevents it to act as a semi-rigid diaphragm in which significant damages including the floor collapse were observed during past earthquakes (Figure 2). The most deficiencies of the traditional un-reinforced masonry buildings are discussed in Section 2 and the detailed seismic rehabilitation procedure is then illustrated in Section 3.

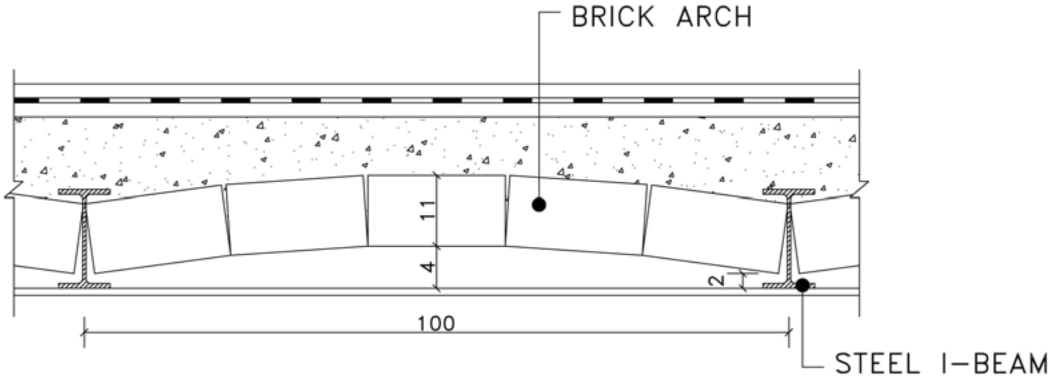

Figure 1. A typical section of steel I-beam jack-arch flooring system (length dimension is cm).

Figure 2. Damage to a traditional jack arch slab during Bam earthquake, 2003 [4].

2 SEISMIC VULNERABILITY ASSESSMENT

The third chapter of the 'Iranian code of practice for the seismic resistant design of buildings, 3rd Edition of Standard No. 2800-05' contains some criteria for designing the URM buildings which are based on engineering judgments and past earthquake experiences [5]. The seismic vulnerability assessment of any URM building can be obtained based on the following criteria.

- Limitations for the number and height of stories and opening dimensions
- Plan's shape and aspect ratio limitations
- Symmetry
- Minimum structural walls
- Complete 3D tie system
- Floor integrity
- Floor to wall connection adequacy

By satisfaction of the above criteria, it is expected that the building can resist against the design (475 years return period) earthquake. It is equivalent to satisfy at least the "Basic Safety Rehabilitation Objective" on the basis of [6]. On the other hand, the main typical deficiencies of URM buildings in Iran can be summarized as Table I. By considering the mentioned deficiencies, in the most cases, the traditional masonry buildings are vulnerable.

Table I. The common deficiency sources in URM buildings in Iran.

Deficiency Source	Description
Floors	Inadequate connection between floor and walls
	No connection between floor components
	Floor is without integrity and diaphragm action performance
Masonry Bearing Walls	Low values for mortar shear strength
	Insufficient shear area in each storey
	Weakness of slender bearing walls due to out of plane force
3D Tie System	Large distance (more than 500 cm in most cases) between vertical tie beams
	Lack of horizontal tie beams in some axes
	Insufficient connection between tie joints
Openings	The short distance between window and the edge of wall
	The long width of window
	The large area of window
Non-Structural Masonry Walls	Weakness of non-structural walls due to out of plane earthquake force
	Insufficient connection with bearing walls (in some cases)

3 SEISMIC REHABILITATION METHODOLOGY

The ASCE 41-06 guidelines [6] introduce eight general strategies for the seismic rehabilitation of buildings which are (1) local modification of components; (2) removal or lessening of existing irregularities; (3) global structural stiffening; (4) global structural strengthening; (5) mass reduction; (6) seismic isolation; (7) supplemental energy dissipation and (8) occupancy changing. A combination of the three mentioned strategies (No. 1, 3 and 4) has been used for the seismic rehabilitation of the Iranian traditional URM buildings. For this purpose the floor integrity has been improved, the wall to wall connection was enhanced and the floor to wall connection was improved. These modifications increase the stiffness and the integrity of the floor as well as changing the boundary condition of bearing walls, load distribution and failure modes. On the other hand, the strengthening of the weak bearing walls and the opening modification has been applied. In this step the strength of the local elements were increased. All the rehabilitation procedures are summarized in this section.

3.1 Openings modification

The openings height or width in the masonry walls has been changed in order to reduce the opening dimensions as well as increasing the coupling beams dimensions. The new part of the masonry wall, as seen in Figure 3, should be connected to the existing part of the masonry wall by enough number of U shape rebars to be able to transfer the shear forces.

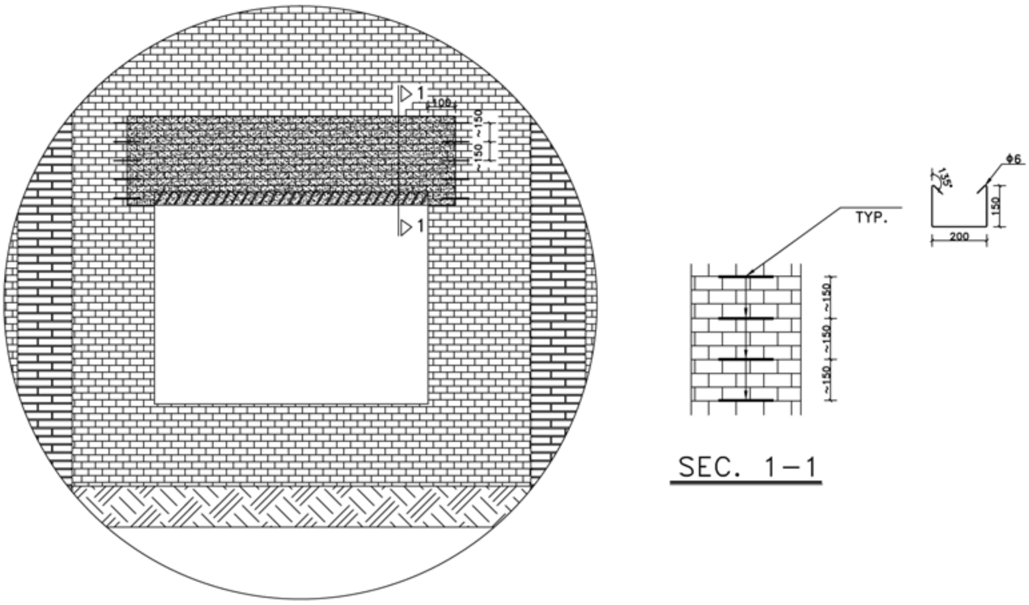

Figure 3. Decreasing of the opening dimensions.

3.2 Floor integrity

The traditional jack arch floor slab, as described in Section 3, can not act as an integrate slab. Hence, $50 \times 5mm$ flat bar was welded to the bottom flange of all steel I beams of the floor as shown in Figure 4. The added bar was welded, at the end, to the steel angle which is in the wall and floor intersection. The last steel I beam joist, which usually has the brick floor in only one side, should be connected to the adjacent I beam steel joist by steel flat bars at each 2 m.

Figure 4. Adding $50 \times 5mm$ steel plates in order to integrate the traditional jack arch slab joists.

3.3 Floor to wall connection

The floor to wall connection, as described in Section 3, is usually without enough strength. That is, a steel angle $60\times60\times6mm$ was added to all intersections between floor and walls. The function of the new angle can be summarized as (1) to connect the floor to the wall; (2) acts as a horizontal tie beam; (3) prevents relative movement of the steel joists in earthquake movements and (4) increases the steel joist support length. The details of the added angel are shown in Figure 5 and Figure 6, respectively, in the case of the floor slab joists are perpendicular or parallel to the wall.

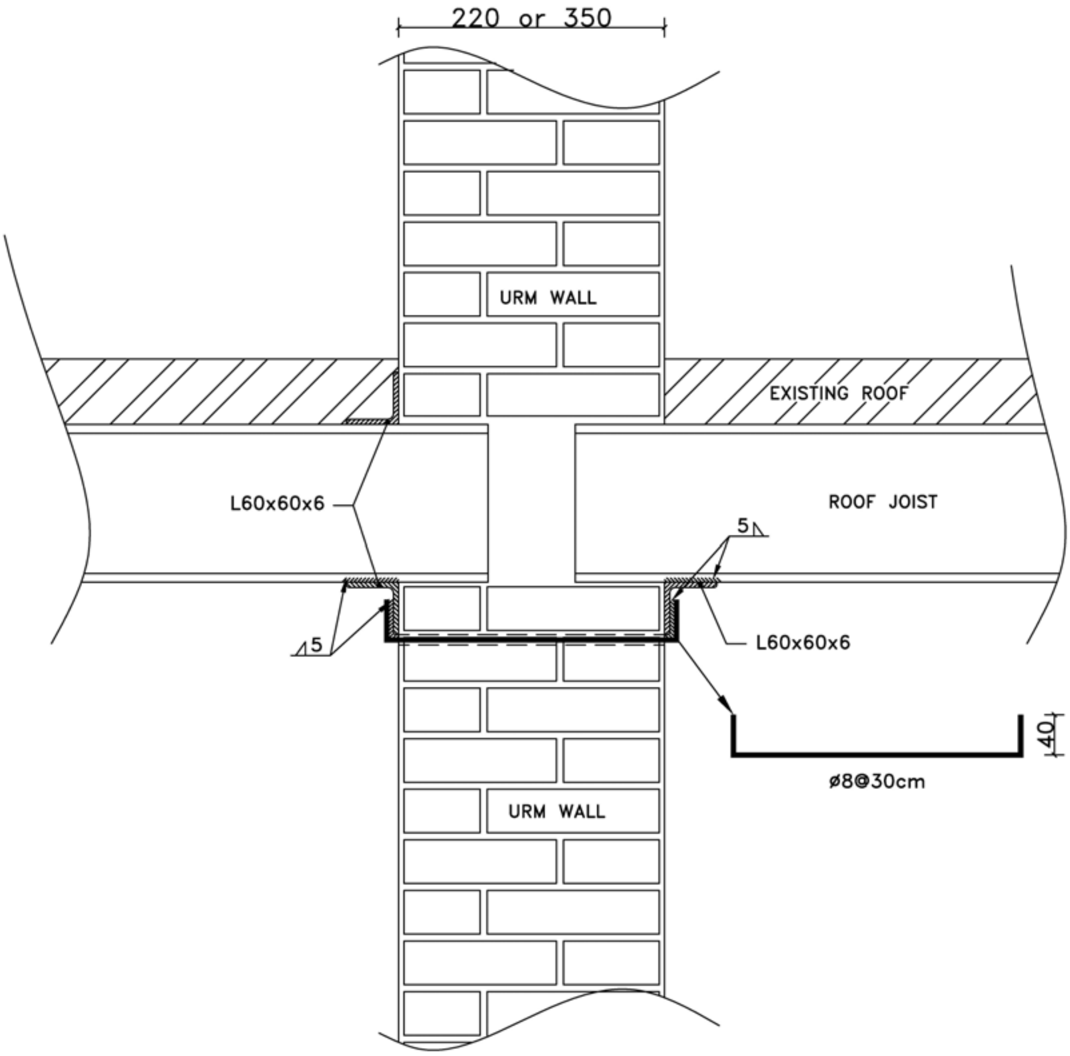

Figure 5. Adding an $60\times60\times6mm$ angle to connect the wall to the floor where the floor slab joists are perpendicular to the wall.

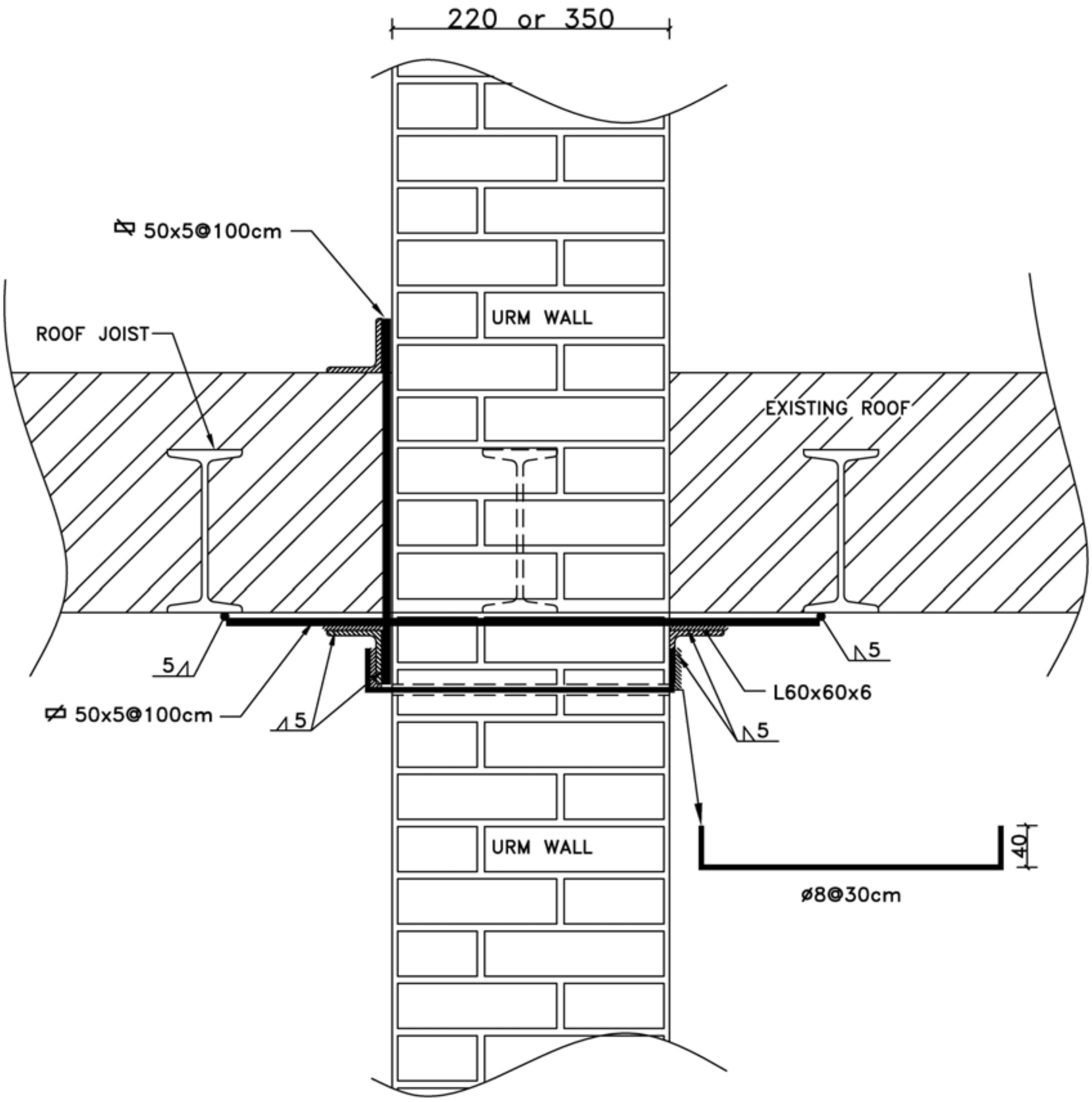

Figure 6. Adding an $60 \times 60 \times 6mm$ angle to connect the wall to the floor where the floor slab joists are parallel to the wall.

3.4 Ties enhancement

There is not any complete 3D tie system in the majority of the URM buildings, as discussed in Section 3. For construction of the 3D tie system, where necessary, a new vertical tie should be executed. Vertical rebars should be implanted in horizontal ties in the top and bottom of the walls. An alternative is the construction of masonry vertical tie beam as seen in Figure 7.

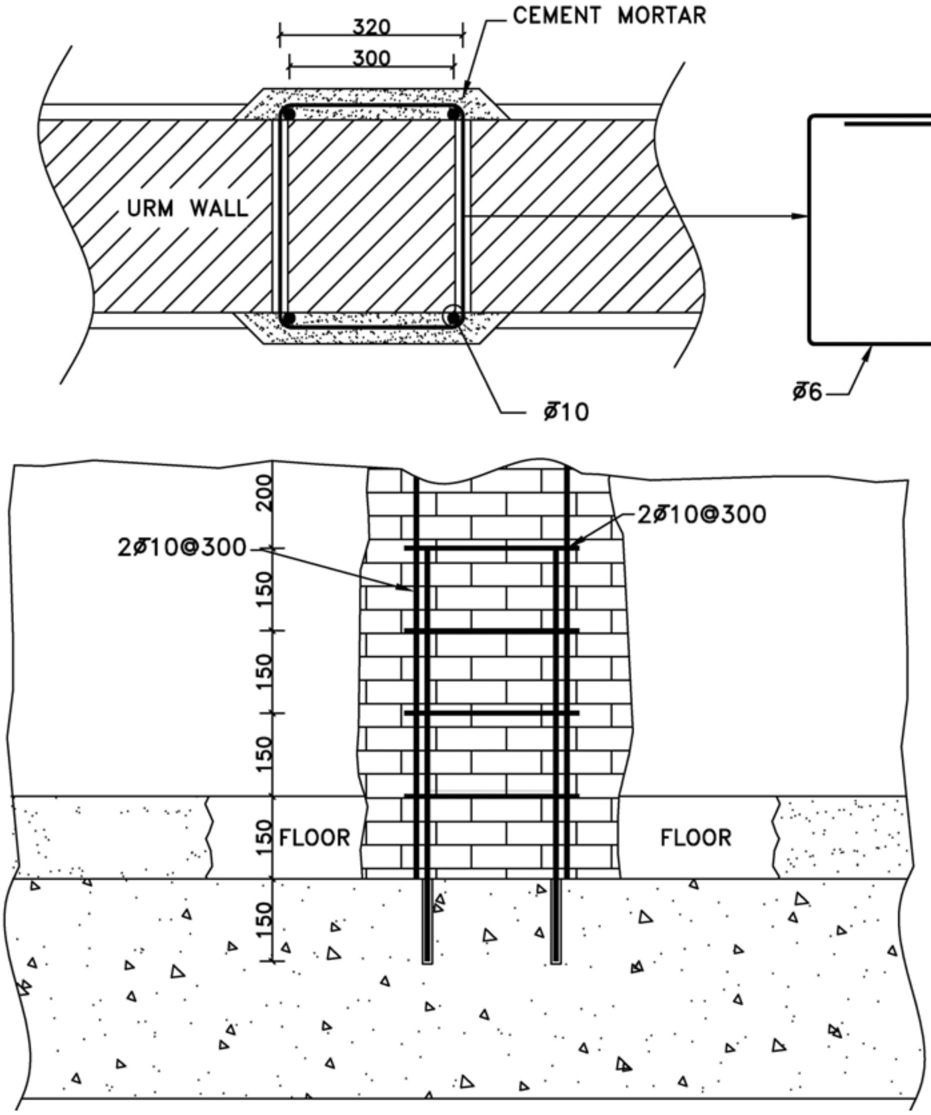

Figure 7. A typical view of the ties enhancement.

3.5 Enhancement of the shear capacity of bearing walls

The masonry wall is enhanced by jacketing with the wire mesh and cement plaster where the capacity of the bearing wall is less than the induced earthquake forces. The details of this method, which is one of the URM wall enhancing methods, can be seen in Figure 8. The enhancement layer should be connected properly to the surrounded ties to be able to transfer the load through stories and deliver it to the foundation. Approximately nine bricks are pulled out from the existing masonry wall, as shown in Figure 9, to make the shear keys between the new layer and the existing masonry wall. The added steel mesh connects to the existing masonry wall by enough number of steel nails. The steel mesh is welded to the corner steel angels, as seen in Figure 10, to make a robust connection between the bearing wall and the floor slab. However the bearing wall is not always without openings. Hence, as shown in Figure 11, the bars should be placed around the openings and the 45° added bars should be placed around the electrical equipment boxes.

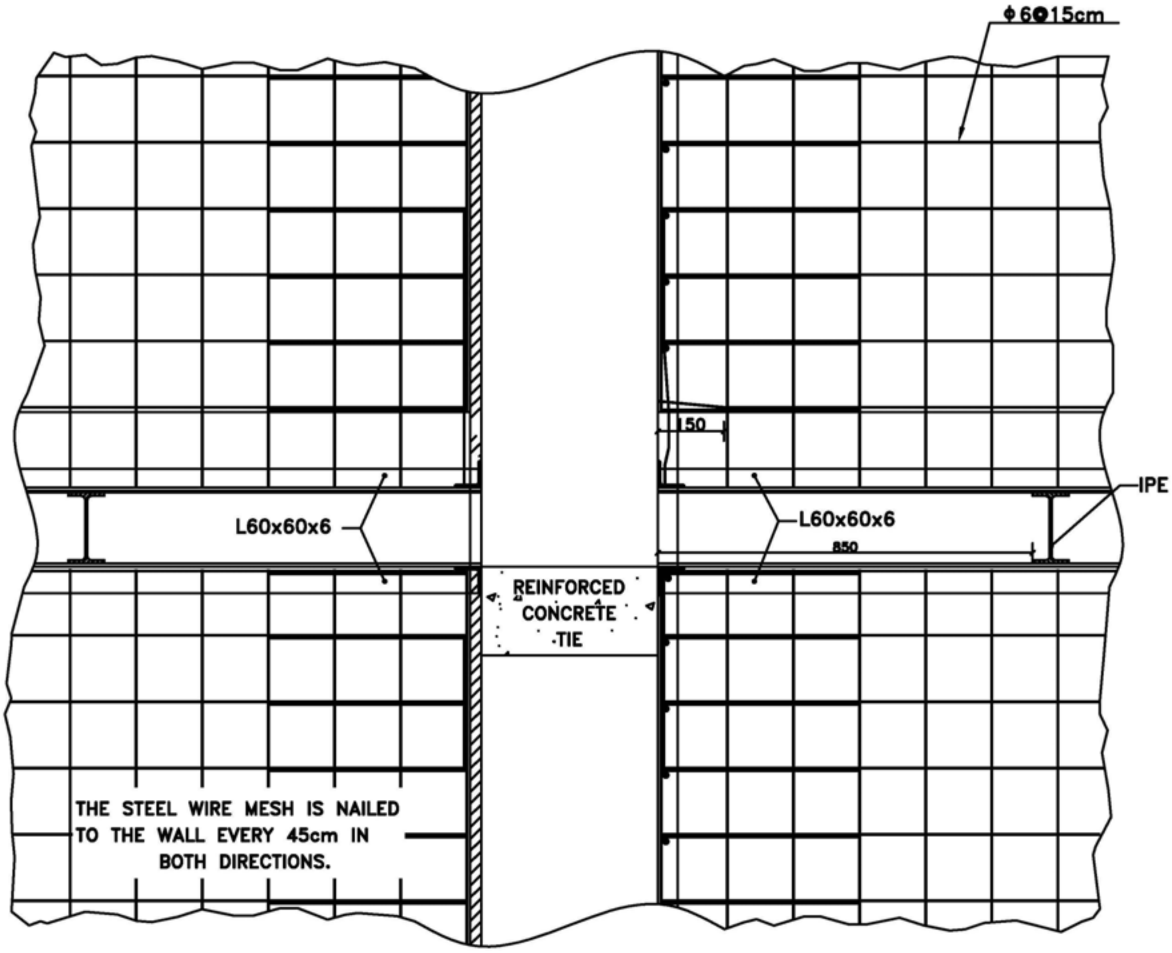

Figure 8. A typical view of the bearing wall enhancement through stories.

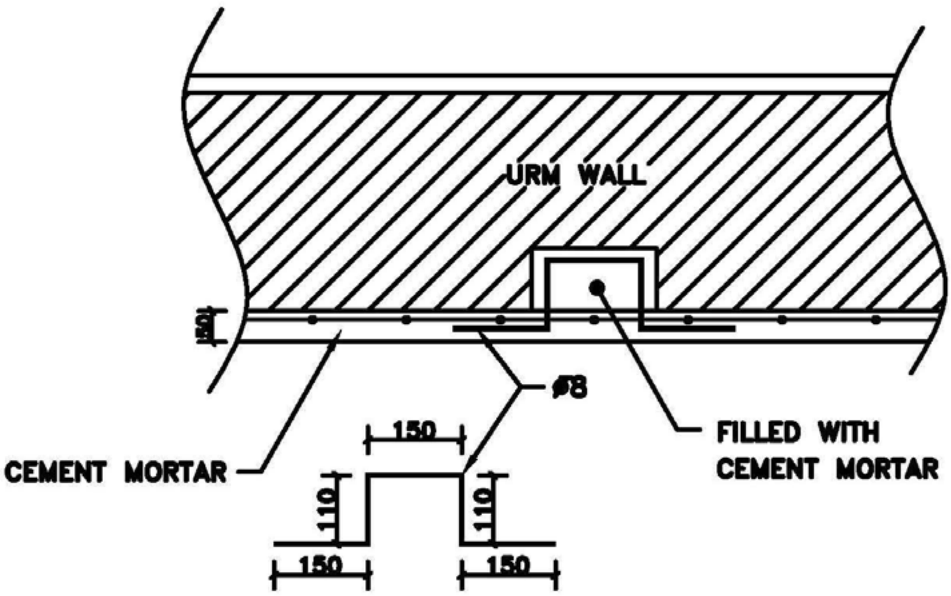

Figure 9. Increasing the strength of the URM wall.

Figure 10. A typical view of the intersection between enhanced bearing walls and floor slab.

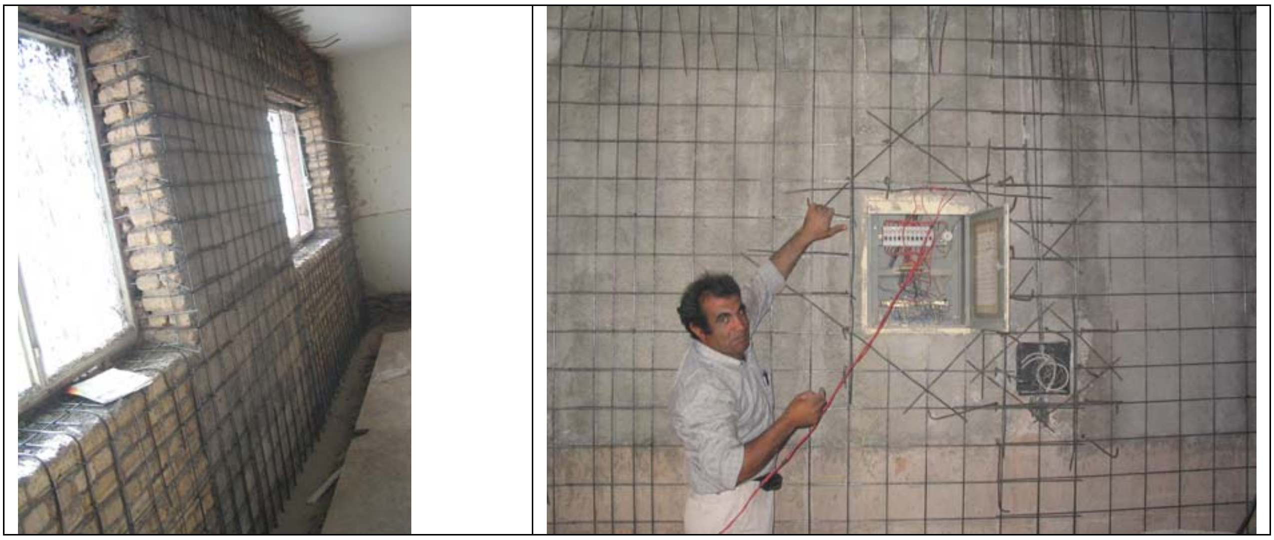

Figure 11. (left) A typical view of the enhanced bearing wall around the openings, (right) A typical view of the enhanced bearing wall around the electrical equipments box.

4 CONCLUSION

A detailed seismic rehabilitation program for a traditional un-reinforced masonry building in Iran has been described in this paper. The walls, floors, openings, and connections were enhanced in order to comply with the code requirements.

The rehabilitation program has been applied to the building under consideration in 50 days. The expense of the project was around 30% of the reconstruction cost which is quite reasonable. The minor architectural modifications were happened mainly in the size of large openings and the overall view has not been changed. This issue is important if it belongs to the client's interest or the building has any historical value.

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